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Theoretical substantiation of the optimal parameters and shape of the working parts of a spring soil leveler

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Abstract. The article presents a theoretical justification for the optimal parameters and shape of the working parts of a spring soil leveler. For this purpose, an effective design scheme for a spring soil leveler was developed. A curved bar consisting of three working surfaces with a toothed comb in the lower part is proposed as a working body of the spring equalizer. Taking into account the physical and mechanical properties of the soils of the Republic of Crimea and the agrotechnical requirements for erosion control treatment, the angles α, β, γ and the dimensions of the compacting-cutting part AB, the leveling part BC and the limiting part CD of the leveling bar of the elastic soil leveler are justified. A theoretical dependence was obtained to determine the required value of the damper stiffness coefficient kd. The range of adjustment of the angle of the leveling bar varies from 15 to 35 degrees. The length of the leveling bars also varies in the range from 140 to 200 mm. The technological train of the developed spring leveler will form a leveled surface and form a ribbed soil microrelief resistant to wind erosion.

1 Introduction

At the present stage of development of agricultural mechanization in the Russian Federation, one of the important elements in the technological operations of combined soil cultivation is the evenness of the surface of the soil layer. The leveled microrelief of the soil has a significant impact on its structure, spraying, water regime, growth and development of plants. An optimally leveled surface of the treated soil makes it possible to uniformly distribute to the required depth from 64 to 72% of the sown seeds of grain crops, while these indicators can decrease to 29–35% if the surface is not well leveled [1, 2].

Analysis of existing soil-cultivating combined units developed by agricultural engineering and their working bodies used to level the surface of the soil microrelief, the main application was found by working bodies that have such a character of movement on the surface as: rotational, vibration, combined, translational. The analysis also shows that the working bodies of soil-cultivating combined units of translational motion have not been sufficiently studied [3].

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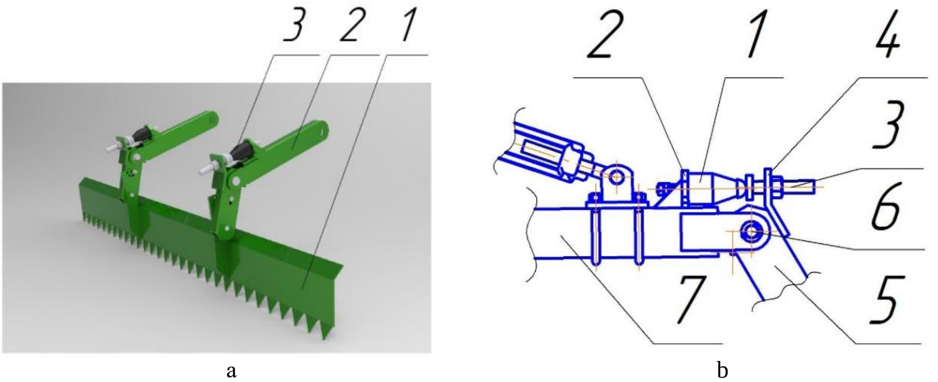
Studies of the works of foreign scientists, such as Francisco P. F. [4], Michael H. [5] showed that when analyzing the study of the impact of leveling working bodies on the soil, the mandatory movement of soil aggregates along the working surface of the leveler was taken as an initial requirement. The study of this analysis of the dynamics of the movement of soil aggregates along the working surface allows us to more accurately describe the process of deformation of the leveled microrelief of the soil profile on the ridges and in the furrows. In addition to this study, it is necessary to take into account the initial characteristics of the leveled soil layer during its interaction with the working body under study. Taking into account the above studies, further substantiation of energy and quality indicators will make it possible to more fully substantiate the rational design parameters and operating modes of the working body of the leveler during soil cultivation [6].

In the works of domestic scientists, the contribution of Academician V.P. Goryachkin deserves special attention. In his works, Vasily Prokhorovich analyzed and substantiated the technological operating modes of both skid-shaped and rotary working bodies. The scientist took as a basis the theory of agricultural mechanics he created [7]. Gabaev A.Kh., when justifying the operation of rotary-type closing working bodies, special attention is paid to the study of furrow-forming linings on the working (sliding) part of the leveler [8].

In order to improve the quality of leveling of the treated soil layer as part of combined soil-cultivating units, leveling devices of various designs, including those using the effect of vibration, are widely used as finishing working bodies [9, 10, 11].

The design of the working parts of the leveler [12] that we have developed consists of a leveling gear bar hinged on an additional frame and a spring mechanism that allows vibrations and copying of the microrelief of the soil surface, as shown in Figure 1. The spring mechanism, as shown in Figure 1 (b), includes a rubber damper, a support that is rigidly attached to a horizontal pipe, and an adjusting bolt. The adjusting bolt itself has a threaded connection to a support, which is rigidly mounted on an inclined profile pipe.



a b

Fig. 1. Proposed design diagram of the leveling device: a – working element of the leveler: 1 – leveling gear bar, 2 – leveler frame, 3 – spring mechanism; b – spring mechanism: 1 – rubber damper; 2 – support; 3 – adjusting bolt; 4 – support; 5 – inclined pipe; 6 – swivel joint; 7 – horizontal pipe.

The purpose of the research is to develop an effective design scheme for a spring soil leveler and theoretical substantiation of the optimal parameters and shape of its working parts.

2 Materials and methods

Theoretical studies were carried out in the department of production mechanization and development of new types of equipment of the Federal State Budgetary Institution of Science

"Research Institute of Agriculture of the Crimea" in 2023-2024. When substantiating the optimal parameters and shape of the working bodies of elastic levelers, the basic provisions of agricultural mechanics, the theory of vibrations, and body movement along a friction plane were used.

3 Results

It is proposed to use a curved bar consisting of three working surfaces with a toothed comb in the lower part as the working body of the spring equalizer. At one point of attachment of the bar to the frame there is a hinge connection, which allows the working element to vibrate, and at the other there is an elastic connection, using a rubber damper. In accordance with the calculation scheme, as shown in Figure 2, it is necessary to justify the parameters of the sealing-cutting part *AB*, the leveling part *BC* and the restrictive part *CD* of the working body.

The leveling part of the aircraft absorbs the main part of the soil resistance when performing the leveling process. Since the angle of attack of the bar is zero, the installation angle β should ensure the mode of loading the soil in front of the working body in the ridge zone and, as a consequence, filling the depressions. To ensure stable operation of the leveling part of the aircraft, the following condition must be met [13]:

$$\beta = \frac{\pi}{2} - arctg(f_S) \tag{1}$$

where f_s is the coefficient of friction between soil and steel.

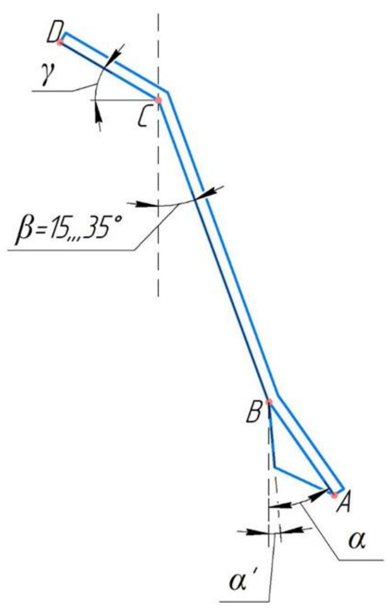


Fig. 2. Calculation diagram for substantiating the parameters of a spring soil leveler.

Taking into account that this working body will be operated in the soil conditions of the Republic of Crimea and the coefficient of soil friction f_s in the region varies from 0.4 to 0.8, the theoretical value of the angle β should be in the range from 21.8 to 38.70. Taking into account the design features of the working body and the expansion of the working range, it is structurally possible to adjust the value of this angle from 15 to 350 in increments of 50.

The sealing-cutting part is a comb consisting of flat teeth of a triangular profile, placed with a pitch *S*, and having additional ribs on its working surface with a cutting edge directed in the direction of movement of the unit. The flat surface of the teeth must be set at an angle α to the vertical, allowing soil particles to slide without loading and creating a compacting vertically directed force. In this case, the angle of installation of the ribs with the cutting edge $\alpha^/$ must ensure the creation of sufficient soil resistance to destroy lumps and cut plant debris, and this is possible in the absence of sliding of the material along the cutting edge.

Since the previously determined angle β corresponds to the beginning of the loading process for a given type of soil, then to ensure a stable sliding process in the section *AB* of the leveling bar, the angle α should be increased to the value:

$$\alpha = \beta + 15 \tag{2}$$

and to ensure supporting crumbling of soil lumps by ribs with a cutting edge, the angle $\alpha^/$ should be reduced to the value:

$$\alpha^/ = \beta - 10 \tag{3}$$

Before starting to operate the unit in new soil conditions, taking into account the actual value of the friction angle, the required angle of position of the comb β is set and the values of the angles α and $\alpha^/$, which are not adjustable relative to it, are automatically ensured.

In order to create an anti-erosion wavy microrelief of the soil after processing and ensure the safety of agronomically valuable soil particles, we take the height of the teeth equal to h_t = 50 mm, and the distance between the comb teeth $b_{c.t.}$ = 10 mm.

The limiting part CD of the leveling bar should prevent soil from spilling over the working element during operation. According to the calculation scheme, as shown in Figure 2, this condition for the initial position corresponding to β = 350 can be written as a formula:

$$AB \cdot \cos\alpha + BC \cdot \cos\beta + CD \cdot \sin\gamma = h_r + h_t \tag{4}$$

where *AB*, *BC*, *CD* are the lengths of the working surfaces of the leveling bar, *AB* = *CD* = 50 mm;

α, β, γ – installation angles of the working surfaces of the leveling bar;

h_r – height of soil ridges;

h_t – technological gap between the level of the soil being leveled and the beginning of the restrictive part *CD*, h_t = 20 mm.

From expression (4) we obtain the dependence for calculating the length of the leveling part *BC*:

$$BC = \frac{h_r + h_t - AB \cdot \cos\alpha - CD \cdot \sin\gamma}{\cos\beta} \tag{5}$$

As a result of calculations using formula (5), provided that the raggedness of the initial field surface does not exceed 0.12 m, the length of the *BC* section should be 0.11 m.

The initial installation angle of the gear bar is adjustable. Its adjustment is carried out by changing the position of the brackets in relation to the inclined profile pipes. The leveling bar has teeth located at the bottom. The teeth themselves are bent from the inner surface of the leveling bar. The shape of the teeth is created in the likeness of isosceles triangles with ribs that are directed forward in the direction of movement of the leveler. A visor is mounted on the top of the leveling bar. It is bent from the inner plane of the bar forward in the direction of movement of the leveler, as shown in Figure 3.

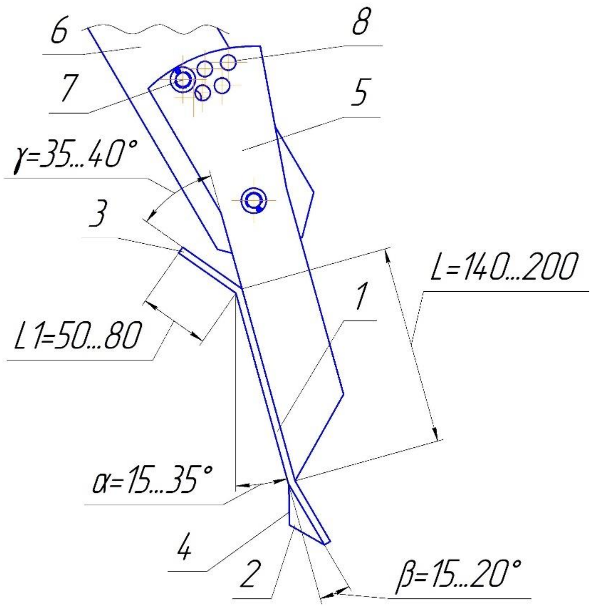


Fig. 3. Working body of the spring soil leveler: 1 – leveling toothed bar; 2 – teeth; 3 – visor; 4 – ribs; 5 – bracket; 6 – inclined profile pipe; 7 – finger; 8 – holes.

The angle of the levelling bar can be adjusted by moving the fingers. The range of adjustment of the angle of the levelling bar varies from 15 to 35 degrees. The length of the levelling bars also varies in the range from 140 to 200 mm.

During operation of the spring equalizer, due to the variable resistance force, periodic vibrations of the equalizer bar relative to the hinge axis will occur. In order to ensure the quality of the technological process, the maximum deviation of the lower part of the gear comb should not exceed $h_{m.d.}$ = 1 cm.

To determine the required rigidity of the elastic damper, we will use the calculation diagram presented in Figure 4.

The equilibrium condition of the system at the maximum permissible rotation of the levelling bar is determined from the formula:

$$F_{e.f.} \cdot r_{e.f.} + m_l \cdot g \cdot r_l = R_r \cdot r_r \tag{6}$$

where $F_{e.f.}$ – the maximum value of the elastic force developed by the damper device;

$r_{e.f.}$ – arm of the force $F_{e.f.}$ relative to the axis of rotation O;

m_l – mass of the levelling bar;

r_l – arm of gravity $m_l g$ of the levelling bar relative to the axis of rotation O;

R_r – soil resistance force;

r_r – arm of the soil resistance force relative to the axis of rotation O.

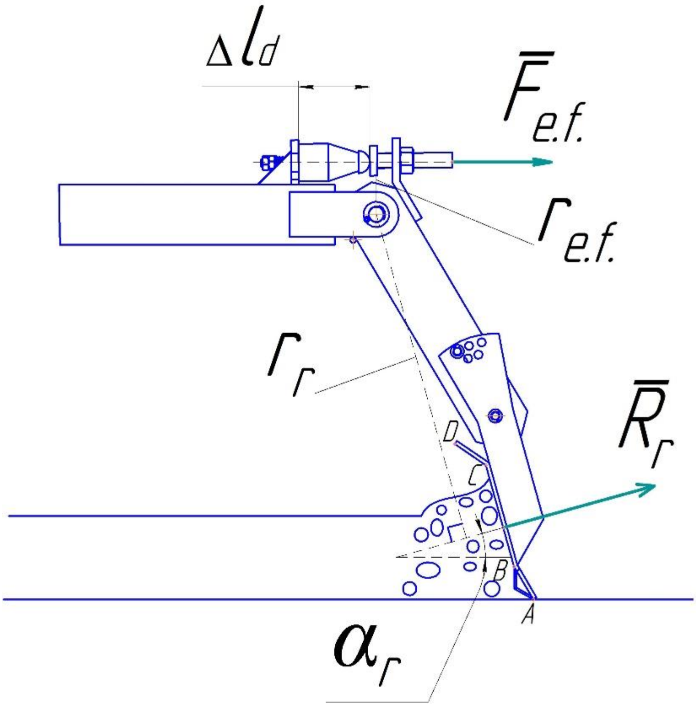


Fig. 4. Calculation scheme for determining the rigidity of an elastic damper.

Let's take into account that:

$$F_{e.f.} = k_d \cdot \Delta l_d \tag{7}$$

where k_d is the damper stiffness coefficient;

Δl_d – value of damper deformation.

Solving equations (6) and (7) together, we obtain the dependence for determining the required value of the damper stiffness coefficient in the form of the formula:

$$k_d = \frac{R_r \cdot r_r - m_l \cdot g \cdot r_l}{\Delta l_d \cdot r_{e.f.}} \tag{8}$$

The permissible value of damper compression Δl_d will be directly proportional to the permissible deviation of the leveling comb from the set stroke depth $h_{m.d.}$ and should not exceed 6 mm.

The working body of the leveler will be a physical pendulum, the frequency of free oscillations of which can be determined by the formula:

$$\nu_l = \frac{1}{T} = \frac{\sqrt{I / mgl}}{2\pi} \tag{9}$$

where I is the moment of inertia of the working body;

m is the mass of the working body;

L is the distance from the center of gravity to the axis of rotation;

g is the acceleration of free fall.

The elastic vibrations of the working body of the leveler that occur during operation intensify the impact of the teeth of the planks on soil lumps, as a result of which the degree of crumbling of soil aggregates further increases.

4 Conclusion

Taking into account the physical and mechanical properties of the soils of the Republic of Crimea and the agrotechnical requirements for erosion control treatment, the angles α, β, γ and the dimensions of the compacting-cutting part *AB*, the leveling part *BC* and the limiting part *CD* of the leveling bar of the elastic soil leveler are justified. A theoretical dependence was obtained to determine the required value of the damper stiffness coefficient k_d. The technological train of the developed spring leveler will form a leveled surface and form a ribbed soil microrelief resistant to wind erosion.

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